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Summary

A group of nuclear submariners was studied to examine whether an 18-h routine imposed by a watch-standing schedule of 6-h on, 12-h off during a prolonged submerged patrol affected the 24-h circadian rhythm in oral temperature, Thayer's activation, Mood "Activity" and Mood "Happiness." The submariners were observed during three sections of the patrol Phase 1, the beginning 8-day period, Phase 2, the middle of the voyage, and Phase 3, the last 7-8 day period of the 10-week voyage The group-synchronized 24-h rhythm in oral temperature disappeared during Phase 3 The group-synchronized 24-h rhythms in Thayer's activation and in Mood "Activity" and "Happiness" disappeared during Phases 2 and 3. A group-synchronized 18-h rhythm was not produced in any of the variables in any Phase of this study, except in during Phase 2 Periodicity analysis of individual's data showed that a loss of 24-h rhythmicity in oral temperature was due not only to reduced circadian amplitude but also to a dispersion of TOPs Loss of 24-h rhythm in "Activation," "Happiness," and "Activity" was predominantly due to a wider dispersion of TOPs The 18-h routine did appear to exert a small modulating effect on rhythmic activity in the variables examined in this study.

Since the sleep-wakefulness cycle was well entrained by the 18-h routine, the submariners experienced a spontaneous internal desynchronization between the activity cycle on the one hand and the cycles of oral temperature and psychological states on the other The performance and health consequences of this chronic dyschronism have yet to be explored We suggest further research to determine the usefulness of an index of synchronization among the physiological and psychological variables, and the relationship of the desynchronizing effects to performance

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This study attempts to determine whether an artificially created short day of 18-h length disrupts the circadian rhythms of oral temperature and "Activation," "Activity," and "Happiness" as determined by a brief adjective checklist. The artificial 18-h day results from the unique 6-h on, 12-h off watch-keeping system employed on U.S. Navy nuclear submarines.

Submariners in the U.S. nuclear fleet are "shift-workers" who live under the strong artificial zeitgeber of an 18-h watch schedule for up to ten weeks during continuously submerged voyages. Previously Schaefer, Kerr, Buss and Haus[20], and Haus (personal communication) have shown that the circadian rhythms of body temperature, pulse rate, and respiration rate of submariners were disrupted by living under 6-h on, 12-h off watched schedules (an 18-h day). Colquhoun, Paine, and Fort[5,6] reported on the circadian rhythm of body temperature of British submariners who stood 4-h watches in a rapidly rotating cycle during a 48-d continuously submerged patrol. They observed that the amplitude of the circadian rhythm of body temperature declined, and only one of eight submariners examined in their study maintained a strong circadian rhythm.

Our study was concerned with a small population of unique shift-workers. Although the shift routine studied is unique to the submarine service, these data should provide new information about the effects of extremely short "days" on the circadian rhythms of oral temperature and psychological states when men work under unbroken, rapidly rotating shift-work schedules for a prolonged time.

Our study intends to follow-up and reexamine the findings of Schaefer et al.[20] by obtaining a new set of data from submariners who lived in a comparable environment where two conflicting zeitgebers were operating: the 24-h social and meal timing schedule and the 18-h watch schedule. Special attention was paid to an observation by Schaefer, et al., which suggested a possible entrainment of physiological functions by the 18-h watch schedule. Entrainment to this schedule is interesting in view of the usually narrow range of entrainment for physiological functions.[1]

MATERIALS AND METHODS

All submariners were adapted to the local time of the submarine base before the start of patrol. In the submarine, four meals were provided: breakfast, lunch, dinner and a lunch-like midnight meal. Shipboard life was paced by the watch-standing schedule, but random events, such as "all hands" drills and "field days" (housekeeping/cleaning), affected the work/rest schedule.

Subjects. The subjects of this study were fifteen submariners, including four U.S. Naval Academy midshipmen, average of 22.9 $\pm$ 4.4 (standard deviation) years (range from 20-35). This group of submariners was part of the crew taking part in the standard deterrence patrol of a Fleet Ballistic Missile (FBM) submarine for a ten-week continuous submergence. The average number of the previous patrols experienced by this group was 2.1 $\pm$ 2.8. Additional details of the subjects in this study are given in Table 1.

Table 1

Demographic Information about Submariners in This Study

Subject	Rating	Age	Years in Submarine Service	Number of Previous Patrols	Sick Calls
1*	ET3	21	2	0	2
2*	RMC	35	15	10	2
3*	SN	20	1	1	4
4	SK3	23	2	4	4
5	MID'N**	20	0.5	0	0
6*	RM2	23	2	3	3
7	MID'N**	21	0 5	0	0
8*	SK3	21	1	2	4
9*	ET3	21	0.5	0	0
10*	QM3	22	1	2	1
11	MID'N**	20	0.5	0	0
12	MID'N**	20	0.5	0	0
13	SN	21	1	2	0
14	STS-1	31	12	6	1
15	ET3	24	0.5	1	1
Average		22.9	2 7	2.1	1.5
SD		4.4	4.8	2.8	1.6
Range		20-35	0.5-15	0-10	0-4

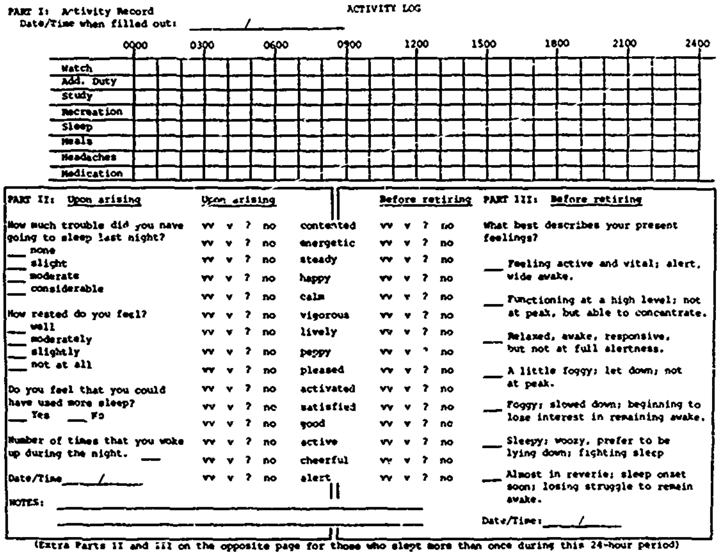
*Participated in all three data collection periods (Phases)
**U.S. Naval Academy Midshipman

Out of fifteen submariners, only seven (subject nos. 1, 2, 3, 6, 7, 9 and 10) were observed in all three Phases (monitoring periods) of this study.

Data Collection Protocol. Phase 1, the first data collection period, started shortly after departure of the submarine for patrol. It continued for eight days, corresponding to Days 4 - 11 of the patrol, to catch any early changes in physiological and psychological states due to living under the 18-h watch schedule. Phase 2, the second data collection period, started on the 34th day of the patrol, and it lasted for 7 or 8 days, covering days 34 - 41 (or 42) of the patrol. Phase 3 the third data collection period, was a period near the end of the patrol, days 60 - 67 Nine days of post-patrol data were obtained from a separate group of submariners a month after the end of the patrol.

For each day of all Phases, oral temperature (Celsius), and mood-adjective checklist estimates of "Activation," "Activity," and "Happiness" (to be described later) were obtained every three hours when the men were awake. Data collections were scheduled at 0100, 0400, 0700, 1000, 1300, 1500, 1900 and 2200. Urine samples were taken for assays of urinary catecholamines, but we did not analyze these data.

Personal Activity Log. To examine work-rest patterns, activation, and moods, subjects filled out the "Personal Activity Log" developed at the Naval Submarine Medical Research Center by Beare et al.[4] (Figure 1).



PART I: Activity Record — ACTIVITY LOG

Date/Time when filled out: ____/________

0000 0300 0600 0900 1200 1500 1800 2100 2400

Watch
Add. Duty
Study
Recreation
Sleep
Meals
Headaches
Medication

PART II: Upon arising

How much trouble did you have going to sleep last night?
___ none
___ slight
___ moderate
___ considerable

How rested do you feel?
___ well
___ moderately
___ slightly
___ not at all

Do you feel that you could have used more sleep?
___ Yes ___ No

Number of times that you woke up during the night. ___

Date/Time____/______

NOTES: ______

Upon arising					Before retiring			
vv	v	?	no	contented	vv	v	?	no
vv	v	?	no	energetic	vv	v	?	no
vv	v	?	no	steady	vv	v	?	no
vv	v	?	no	happy	vv	v	?	no
vv	v	?	no	calm	vv	v	?	no
vv	v	?	no	vigorous	vv	v	?	no
vv	v	?	no	lively	vv	v	?	no
vv	v	?	no	peppy	vv	v	?	no
vv	v	?	no	pleased	vv	v	?	no
vv	v	?	no	activated	vv	v	?	no
vv	v	?	no	satisfied	vv	v	?	no
vv	v	?	no	good	vv	v	?	no
vv	v	?	no	active	vv	v	?	no
vv	v	?	no	cheerful	vv	v	?	no
vv	v	?	no	alert	vv	v	?	no

PART III: Before retiring

What best describes your present feelings?

___ Feeling active and vital; alert, wide awake.
___ Functioning at a high level; not at peak, but able to concentrate.
___ Relaxed, awake, responsive, but not at full alertness.
___ A little foggy; let down; not at peak.
___ Foggy; slowed down; beginning to lose interest in remaining awake.
___ Sleepy; woozy, prefer to be lying down; fighting sleep
___ Almost in reverie; sleep onset soon; losing struggle to remain awake.

Date/Time:____/______

(Extra Parts II and III on the opposite page for those who slept more than once during this 24-hour period)

Figure 1

Each page of the log book contains three parts. Part I is a 24-h activity record, consisting of eight rows on the top of the page. Submariners indicated what they had been doing by drawing a line in one of the appropriate rows: standing watch, performing additional duty, studying, etc. Part II is a set of five questions about sleep quality and feeling upon awakening. Part III used the Stanford Sleepiness Scale.[10] A description of the quantity and regularity of sleep is reported elsewhere.[4] The middle of the log is a list of fifteen adjectives taken from the work of Ryman, Biersner and La Rocco[19], and Thayer[26] to measure moods. Mood "Happiness" (MH) was measured by the subject's description of his present feelings by choosing one of the four response categories for each of seven adjectives: contented, calm, steady, happy, satisfied, good, and pleased. Mood

"Activity" (MA) was similarly measured by six adjectives lively, active, energetic, cheerful, vigorous, and alert. Thayer's[26] Activation scale (TA) was used to measure subjective feelings-of-being-active by six adjectives lively, active, energetic, vigorous, activated, and happy. The MA and TA scales share four adjectives, and thus are highly correlated.

Subjects were instructed to complete the activity record, Stanford Sleepiness Scale (SSS), and the mood scale before retiring to a sleep period. Upon awakening, they completed the sleep quality questions and the mood scale. Two additional sleep quality questions sets, and four additional sets of the mood scale are printed on the back of each Personal Activity Log page for use in the (usual) event that more than one sleep period was taken in 24-h.

Analyses. In analyzing the sleep-wakefulness cycle, an inter-sleep interval or an inter-wake interval can be used. The inter-sleep interval is the time elapsed between one sleep onset to the onset of the next sleep period. The inter-wake interval is similarly defined. Variability in the inter-sleep intervals can be used to express stability, or the relative strength, or periodicity in sleep-wakefulness data: the smaller the variability, the stronger will be the rhythmicity.

Analysis based on the inter-sleep interval cannot specifically reveal the strength of many rhythm components in data. Thus, a different analysis was used in this paper. Each 30-minute epoch of the 24-h day was categorized, on the basis of entries in the Personel Activity Log, as either awake or asleep. Awake epochs were coded by one's, and sleep epochs by zero's. Then, an autocorrelation function was determined for this string of 1's and zero's, using 33% of the data length as the maximal lag. The autocorrelation function used was a cosine wave which enhanced the periodicity in the original sleep-wakefulness data.

In order to numerically extract periods and strengths of the rhythm, a non-orthogonal "cosine transform" was applied to the autocorrelation function. To complete a "cosine transform," forty-five cosine waves, whose periods were pre-selected to vary from 360 min (6-h) to 1680 min (28-h) in incremental steps of 30 min, were generated by a computer. Then a Pearson product-moment correlation (r) was calculated between the autocorrelation function and each of these cosine waves. Each of the correlation coefficients was squared (r^2) to express the percentage of variance in the autocorrelation function accounted for by the cosine wave of a given period. This r^2 value indicates the strength of the rhythm in the sleep-wakefulness data at the period of the cosine wave used. The maximal r^2 possible is 1.00, while an r^2 approaching zero indicates little or no rhythm.

Cosine waves of pre-selected periods were directly fitted to the individual's data for each of three Phases to determine the period and strength of rhythms in oral temperature and subjective feelings of each man. The data were scanned to determine whether they exhibited rhythmic activity at twenty pre-selected periods. 8-h/c, 12-h/c, 16- to 28-h/c in one-hour intervals, and 32- and 48-h/c in four-hour intervals. The fit of each cosine wave yields amplitude, acrophase angle or Time-of-Peak (TOP), and r^2. Again, the value r^2 expresses the percent of the variance in the data which can be accounted for by the cosine wave fitted. The mathematical basis of fitting cosine waves to the data has been discussed by Halberg, Tong, and Johnson[8], and Nelson, Tong, Lee, and Halberg[17].

Colquhoun et al.[5] observed that the method of fitting a single cosine wave became progressively less appropriate for British submariners who lived in the community of the submarine, cut off from natural 24-h zeitgebers. They reported that the use of two cosine waves, one with a 24-h period and another with a 12-h period, improved the representation of circadian wave-form in both temperature, especially the estimation of TOP. A similar bisinusoidal (two-wave) analysis was proposed by Naitoh, Lubin and Colquhoun[16]. In the present study, two cosine waves, each having a different period, were fitted to the data. Unlike the "combined curve" of Colquhoun et al.[5], however, we fitted all possible combinations of the twenty preselected periods. Altogether 190 bisinusoidal waves were fitted to data obtained at each Phase for each submariner. The best fitting combined curve was defined as that which achieved the largest r^2 value. The program for fitting the cosine waves was written in Fortran IV, and executed by an IBM 370 computer.

So far, we have described the analysis of rhythms in individuals' data. To find the group-synchronized rhythm, the group-mean-cosinor method[8,9,17] was used. This method summarizes and determines an inferential statistical value from the amplitudes and acrophase angles of grouped data. In a cosinor plot, when a 90% or 95% confidence ellipse, defined by a group of the paired values of amplitude and acrophase angle, does not overlay the pole, it indicates that a significant rhythmic component at either the 10% or 5% level of significance[†] or better was found for the group. The group-mean-cosinor analysis (GMCA) evaluates pairs of amplitude and acrophase angles simultaneously (as vectors) to determine the statistical significance of the rhythmic components. It does not independently evaluate whether the amplitudes were changed for a significant majority of submariners, or whether the acrophase angles were the only aspect of the rhythm altered. To evaluate the change in the circadian amplitude of the group, a t-test for correlated means was used. The Rayleigh test for directional data as described by Batschelet[2,3] was employed to evaluate the change in a group of acrophase angles.

RESULTS

<u>Sleep-Wakefulness Cycle During the Patrol</u>. Figure 2 shows each day (activity cycle) appearing below the last. The bars represent periods of wakefulness (black) and sleep (white). The "objective" day is usually defined as one wake period followed by one sleep period. A temporally correct redrawing (see, for example, Wever[27], p. 61) was not made for this Figure so that one "wake-sleep" cycle may have more than one sleep episode. The X-axis of the diagram consists of four cycles of 24-h to show the shifting of the objective day due to the 18-h routine. The data in Figure 2 was taken from submariner No. 14 during Phase 1 of the patrol. His sleep patterns during Phase 1 are given in the insert. He slept an average of 8.03 hours per 24-h period. Average duration of each sleep episode was 4.72 hours, and, on the average, he slept 1.71 times per 24-h period. Figure 2 shows a pronounced 18-h sleep-wakefulness rhythm, in spite of the frequent napping.

[†]Unless specified otherwise, significance in the present paper refers to at least 5% level, two tails.

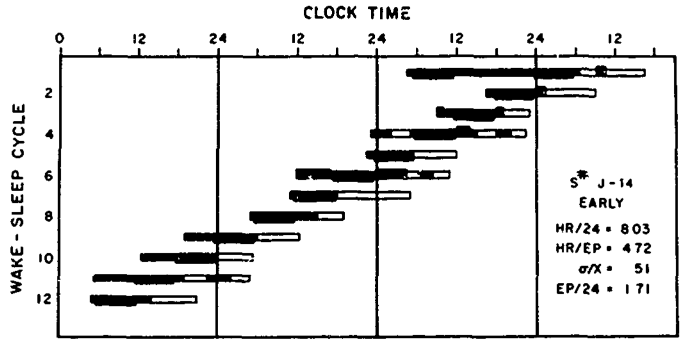


Figure 2

During Phase 1, eleven of the 15 subjects' logs provided sufficiently detailed data for analysis of the sleep-wakefulness cycle. The average sleep-wakefulness cycle during Phase 1 had a 1113 min (roughly 18.5-h) period with an r^2 of 0.677 ± 0.162 Six of these 11 subjects also exhibited a secondary rhythmic component. Its average period was 1516 min (roughly 25 3-h) with an r^2 of - 249 ± 0 0091

During Phase 2, eight of the 15 men provided sufficiently detailed log data for analysis of the sleep-wakefulness cycle. The average period was 1121 min (roughly 18.7-h) with an r^2 of 0 666 ± 0 285 Four of these eight submariners also showed a secondary peak at an average period of 1500 min (25-h) with an average r^2 of 0.271 ± -.140.

In Phase 3, seven of the 15 men provided sleep-wakefulness data. The average sleep-wakefulness cycle had a period of 1144 min (roughly 19.1-h) with an r^2 of 0.733 ± 0.109. Only two of these men had a secondary peak one at 1605 min/cycle (26.75-h) and another at an extremely short cycle of 630 min (10.5-h).

During the post-patrol phase, a return to normal habitual patterns of sleep-wakefulness was observed. Only six of the original 15 subjects returned Personal Activity Logs which allowed calculation of the sleep-wakefulness cycle. Five of these six showed the expected pattern an average period of 1446 min (roughly 24.1-h) with an average r^2 of 0 926 ± 0.075 That is, 93% of the variance in their sleep-wakefulness cycle could be accounted for by the 24.1 rhythm One man (a Midshipman) did, however, show an unusual sleep-wakefulness cycle a mixture of 720 min (12-h, r^2 = 0.501) and of 1500 min (25-h, r^2 = 0.408) periods.

<u>Oral Temperature</u>: Figure 3 shows chronograms of oral temperature from subject No. 1 on the left-hand side, and plexograms of the same information on the right-hand side The chronograms display oral temperature readings over time of day for up to 8 consecutive days during Phases 1, 2, and 3. The plexograms display the same data collapsed into a single 24-h period, ignoring

the day of data collection. The plexograms were developed on the basis of Buys-Ballot tables (Enright[7]; Orth, Besser, King, and Nicholson[18]).

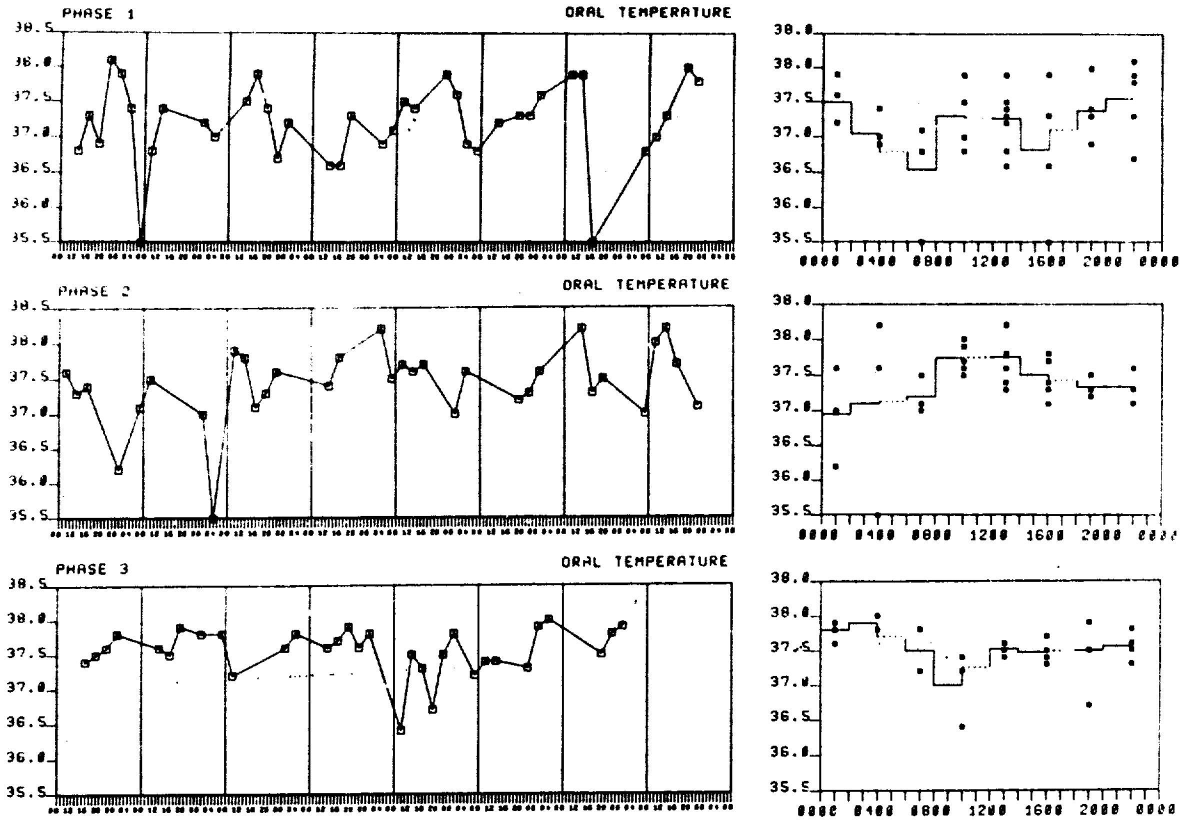


Figure 3

The plexograms appear to show the typical early morning circadian "dip" in oral temperature during Phase 1 only.

Tables 2A and 2B present the basic observation of this study. The top half of Table 2A shows the amplitudes and TOP's (the time of day corresponding to the calculated acrophase angle) of the 24-h rhythmic component in oral temperature of fifteen submariners.

A treatment by subjects analysis of variance showed that the 24-h amplitudes of oral temperature in Phases 1 (0.29°C) and 2 (0.25°C) did not differ significantly ($F < 1$). The mean oral temperature increased slightly, from 36.89°C in Phase 1 to 37.03° in Phase 2 ($F(1,11) = 10.92$, $p <$ .01). For the seven men participating in all three Phases, the 24-h amplitudes averaged 0.30°, 0.22°, and 0.19° in the respective periods. This apparent decrease is marginally significant (($F(2,12) = 3.05$, $p < .10$). For these men, the mean oral temperature increased steadily during the patrol, going from 36.97° to 37.06° to 37.19°C ($F(2,12) = 10.72$, $p < .01$).

TABLE 2A 24-h rhythm characteristics of submariners during a ten-week long patrol under 18-h watch schedule.

	PHASE 1 (4d–11d)				PHASE 2 (34d–42d)				PHASE 3 (60d–67d)			
SUBJ	AMP	TOP	MEAN	SD	AMP	TOP	MEAN	SD	AMP	TOP	MEAN	SD
ORAL TEMPERATURE												
1*	0.30	20:23	37.19	0.66	0.33	13:02	37.42	0.54	0.19	01:26	37.58	0.29
2*	0.33	21:45	36.88	0.39	0.02	14:42	36.99	0.42	0.09	09:11	37.09	0.23
3*	0.23	20:25	37.35	0.53	0.26	17:07	37.43	0.38	0.19	04:24	37.49	0.35
4	0.03	09:36	36.93	0.58	0.16	14:44	37.08	0.45	--	--	--	--
5	0.52	19:25	36.71	0.63	0.23	21:50	36.73	0.62	--	--	--	--
6*	0.18	18:48	36.95	0.51	0.18	18:43	36.89	0.52	0.13	11:23	37.10	0.30
7	0.27	01:55	36.40	0.56	0.36	20:57	36.90	0.48	--	--	--	--
8*	0.41	22:26	36.97	0.50	0.36	13:55	36.96	0.40	0.18	05:35	36.91	0.34
9*	0.32	19:45	36.60	0.60	0.30	20:04	36.70	0.46	0.37	22:42	36.97	0.39
10*	0.33	21:29	36.84	0.69	0.07	06:11	37.04	0.36	0.19	19:52	37.17	0.26
11	0.30	19:54	36.76	0.54	0.61	20:21	36.90	0.61	--	--	--	--
12	0.31	21:27	37.15	0.46	0.16	07:04	37.33	0.55	--	--	--	--
13	--	--	--	--	--	--	--	--	0.25	17:52	36.94	0.42
14	--	--	--	--	--	--	--	--	0.34	12:06	36.95	0.40
15	--	--	--	--	--	--	--	--	0.17	14:01	36.89	0.33
Mean	0.29		36.89		0.25		37.03		0.21		37.11	
SD	0.12		0.26		0.16		0.25		0.09		0.24	
THAYER'S ACTIVATION (TA)												
1*	0.17	17:26	1.42	0.37	0.07	09:46	1.51	0.37	0.17	20:42	1.43	0.27
2*	0.35	22:09	2.30	1.14	0.14	11:35	2.11	0.60	0.09	06:38	2.25	0.44
3*	0.08	10:00	2.03	0.38	0.10	05:42	2.02	0.39	0.19	08:18	2.04	0.25
4	0.17	00:42	1.96	0.46	0.13	15:35	1.74	0.29	--	--	--	--
5	0.22	01:04	2.31	0.47	0.16	05:42	2.15	0.30	--	--	--	--
6*	0.10	20:08	2.12	0.68	0.38	18:35	3.11	0.74	0.36	12:02	3.22	0.60
7	0.26	19:37	1.76	0.35	0.34	18:58	1.82	0.44	--	--	--	--
8*	0.34	23:04	2.01	0.64	0.19	04:40	1.97	0.46	0.27	08:07	2.23	0.57
9*	0.23	19:09	2.08	0.57	0.29	18:24	2.20	0.53	0.52	23:46	2.24	0.58
10*	0.10	18:16	2.96	0.45	0.18	21:53	2.57	0.47	0.26	21:59	2.79	0.54
11	0.08	18:42	2.04	0.27	0.07	02:37	1.93	0.21	--	--	--	--
12	0.06	12:38	2.59	0.71	0.42	01:53	2.43	0.59	--	--	--	--
13	--	--	--	--	--	--	--	--	0.22	13:18	2.77	0.46
14	--	--	--	--	--	--	--	--	0.34	18:42	2.52	0.61
15	--	--	--	--	--	--	--	--	0.24	12:10	1.91	0.87
Mean	0.18		2.13		0.21		2.13		0.27		2.34	
SD	0.10		0.39		0.12		0.42		0.12		0.51	

TABLE 2B 24-h rhythm characteristics of submariners during a ten-week long patrol under 18-h watch schedule.

	PHASE 1 (4d–11d)				PHASE 2 (34d–42d)				PHASE 3 (60d–67d)			
SUBJ	AMP	TOP	MEAN	SD	AMP	TOP	MEAN	SD	AMP	TOP	MEAN	SD
MOOD "ACTIVITY"												
1*	0.20	19:06	1.77	0.48	0.11	09:14	1.85	0.49	0.28	20:58	1.75	0.39
2*	0.30	21:43	2.64	0.92	0.07	15:17	2.38	0.58	0.16	05:23	2.52	0.39
3*	0.10	12:22	2.64	0.47	0.17	08:53	2.43	0.33	0.26	08:20	2.56	0.37
4	0.19	00:28	1.86	0.45	0.10	15:53	1.77	0.28	--	--	--	--
5	0.22	00:42	2.46	0.41	0.14	05:42	2.22	0.26	--	--	--	--
6*	0.11	21:00	2.16	0.65	0.32	18:26	3.19	0.66	0.34	12:15	3.15	0.57
7	0.18	20:16	2.13	0.28	0.22	18:29	2.02	0.34	--	--	--	--
8*	0.34	22:14	2.16	0.65	0.17	07:54	2.05	0.48	0.39	08:23	2.35	0.60
9*	0.18	20:18	2.20	0.53	0.31	18:37	2.33	0.50	0.51	00:14	2.33	0.55
10*	0.11	17:16	3.02	0.38	0.31	14:53	2.90	1.12	0.29	21:54	2.77	0.63
11	0.10	21:28	2.33	0.27	0.03	02:38	2.21	1.19	--	--	--	--
12	0.05	10:45	2.66	0.67	0.52	02:34	2.56	0.60	--	--	--	--
13	--	--	--	--	--	--	--	--	0.17	13:08	2.93	0.43
14	--	--	--	--	--	--	--	--	0.19	19:28	2.73	0.51
15	--	--	--	--	--	--	--	--	0.21	13:17	2.05	0.78
Mean	0.17		2.34		0.21		2.33		0.28		2.51	
SD	0.09		0.36		0.14		0.41		0.11		0.42	
MOOD "HAPPINESS"												
1*	0.14	18:14	1.77	0.33	0.11	08:18	1.88	0.35	0.17	22:22	1.72	0.24
2*	0.24	23:36	2.86	0.46	0.12	16:51	2.35	0.45	0.09	05:14	2.24	0.21
3*	0.09	03:53	2.60	0.44	0.07	08:20	2.60	0.39	0.38	08:12	2.69	0.50
4	3.22	23:44	1.77	0.47	0.01	13:11	1.64	0.25	--	--	--	--
5	0.07	23:53	2.46	0.30	0.10	20:08	2.14	0.33	--	--	--	--
6*	0.22	19:16	2.61	0.64	0.31	20:14	3.40	0.64	0.33	13:17	3.23	0.53
7	0.10	20:34	2.56	0.42	0.09	07:29	2.46	0.45	--	--	--	--
8*	0.28	23:00	2.04	0.54	0.04	07:34	2.18	0.40	0.19	07:23	2.50	0.46
9*	0.18	23:23	2.29	0.58	0.13	21:20	2.50	0.55	0.36	00:54	2.22	0.63
10*	0.07	19:00	2.97	0.29	0.13	02:19	2.67	0.37	0.27	21:11	2.68	0.59
11	0.08	21:07	2.50	0.26	0.04	06:49	2.38	0.23	--	--	--	--
12	0.08	09:56	2.56	0.63	0.41	02:53	2.45	0.58	--	--	--	--
13	--	--	--	--	--	--	--	--	0.02	10:25	2.96	0.28
14	--	--	--	--	--	--	--	--	0.26	20:44	3.12	0.47
15	--	--	--	--	--	--	--	--	0.02	12:23	2.42	0.71
Mean	0.15		2.42		0.13		2.39		0.21		2.58	
SD	0.08		0.38		0.12		0.44		0.13		0.46	

To summarize, the average oral temperature increased slightly (0.22°C) over the course of the 10-week patrol, and the increase in average temperature appears to have been accompanied by a marginally significant decrease in the amplitude of the daily variation.

One of the more critical questions concerns how long a group-synchronized 24-h rhythm in oral temperature survived in this environment. The group-mean-cosinor analysis (GMCA) answers this question. A group-synchronized rhythm means that a majority of the members of the group have similar TOP's and comparable amplitudes. While submerged, the submarine environment lacks many of the natural 24-h zeitgebers. The 24-h social and (to a smaller extent) meal-timing cues are present, but they are in competition with a very strong zeitgeber provided by the 18-h watch routine.

We were unable to obtain a baseline observation of oral temperature rhythm on a 24-h schedule, but the results from other studies (such as Naitoh[15]; Haus, personal communication; and Naitoh, et al.[16] provide a basis for comparison. A GMCA was performed on the amplitudes and acrophase angles of the twelve men participating in Phases 1 and 2. The results of this analysis are given in Table 3. The analysis of Phase 3 was based on records from ten subjects.

TABLE 3 Results of group-mean-cosinor analysis.*

	PHASE 1 (4d - 11d)		PHASE 2 (34d - 42d)		PHASE 3 (60d - 67d)	
GROUP-SYNCHRONIZED 24-h RHYTHM						
Oral temperature (°C)	TOP	$20^{38}(19^{31} - 22^{53})$	TOP:	$18^{16}(12^{14} - 21^{44})$	TOP:	Undefined
	AMP	0.259(0.144 - 0.379)	AMP	0.144(0.010 - 0.319)	AMP:	Undefined
Thayer's Activation	TOP	$21^{10}(16^{38} - 23^{53})$	TOP:	Undefined	TOP:	Undefined
	AMP	0.127(0.021 - 0.235)	AMP:	Undefined	AMP:	Undefined
Mood "Activity"	TOP	$21^{33}(17^{37} - 23^{32})$	TOP:	Undefined	TOP:	Undefined
	AMP	0.130(0.031 - 0.235)	AMP:	Undefined	AMP:	Undefined
Mood "Happiness"	TOP:	$22^{10}(18^{32} - 23^{12})$	TOP:	Undefined	TOP:	Undefined
	AMP	0.108(0.023 - 0.195)	AMP:	Undefined	AMP:	Undefined
GROUP-SYNCHRONIZED 18-h RHYTHM						
Oral temperature	TOP	Undefined	TOP:	Undefined	TOP:	Undefined
	AMP	Undefined	AMP	Undefined	AMP:	Undefined
Thayer's Activation	TOP:	Undefined	TOP:	Undefined	TOP:	Undefined
	AMP:	Undefined	AMP:	Undefined	AMP:	Undefined
Mood "Activity"	TOP:	Undefined	TOP:	Undefined	TOP:	Undefined
	AMP	Undefined	AMP:	Undefined	AMP:	Undefined
Mood "Happiness"	TOP:	Undefined	TOP:	$23^{49}(19^{46} - 04^{38})$	TOP:	Undefined
	AMP:	Undefined	AMP:	0.076(0.013 - 0.146)	AMP:	Undefined

A group of twelve submariners provided the data for Phases 1 and 2. Ten submariners provided the data for Phase 3.
TOP = Time-of-Peak, AMP = Amplitude of rhythm.
*95% Confidence Interval

A group-synchronized rhythm of oral temperature was found to persist among the submariners during Phases 1 and 2. It was lost, however, during Phase 3.

The average 24-h oral temperature amplitude for the twelve men during Phase 1 was 0.26°C (0.47 F). Naitoh[15] observed that a group of 23 young Navy recruits showed a 24-h oral temperature amplitude of 0.50°F during a baseline period, which is directly comparable to the submariners' data. Haus, however, found the 24-h oral temperature amplitude was 0.79°F in a group of seven submariners studied during the outfitting period by Schaefer et al. This is considerably larger than the amplitude exhibited by our subjects during Phase 1. It is, thus, uncertain whether the 24-h oral temperature amplitude had changed during Phase 1.

During Phase 1, the average TOP determined for the 24-h oral temperature rhythm for twelve men in this study was 20^{58}, with a 95% confidence interval of 19^{31} to 22^{53} (see Table 3). The average TOP found by Naitoh[15] was 17^{22}. Haus found that the average TOP of his sample of seven submariners during the baseline period was 18^{04}. A group of 73 young Royal Navy ratings was reported to have the average TOP at 17^{11} (see Naitoh, et al.[16]). Thus, the average TOP of the submariners seems to have been delayed from 3 to 4 hours.

During Phase 2, a considerable weakening of the group-synchronized oral temperature rhythm was found. The average TOP was at 18^{16}, well within the 95% confidence time boundaries for the above-mentioned reference groups. But the 24-h oral temperature amplitude was reduced to almost one-half of the amplitude seen in Phase 1, and the width of the 95% confidence interval was 9.5-h, three times that of Phase 1.

The GMCA of the seven men who participated in all three Phases of this study is depicted in Figure 4. Figure 4 shows three plexograms (the left-hand side) and a cosinor plot (the right-hand side, top) for this group of seven men. As shown by the cosinor plot, Phase 1 data exhibited a group-synchronized 24-h rhythm in oral temperature. The confidence ellipse for the Phase 1 data is identified by 1 in this figure. The average TOP was at 20^{57} with a 95% confidence interval of 18^{43} to 22^{18}. The plexogram for Phase 2 shows a dip around 0400, suggesting a normal circadian rhythm. But the GMCA failed to show a significant group-synchronized rhythm (ellipse 2). During Phase 3, no group-synchronized 24-h rhythm for oral temperature was found.

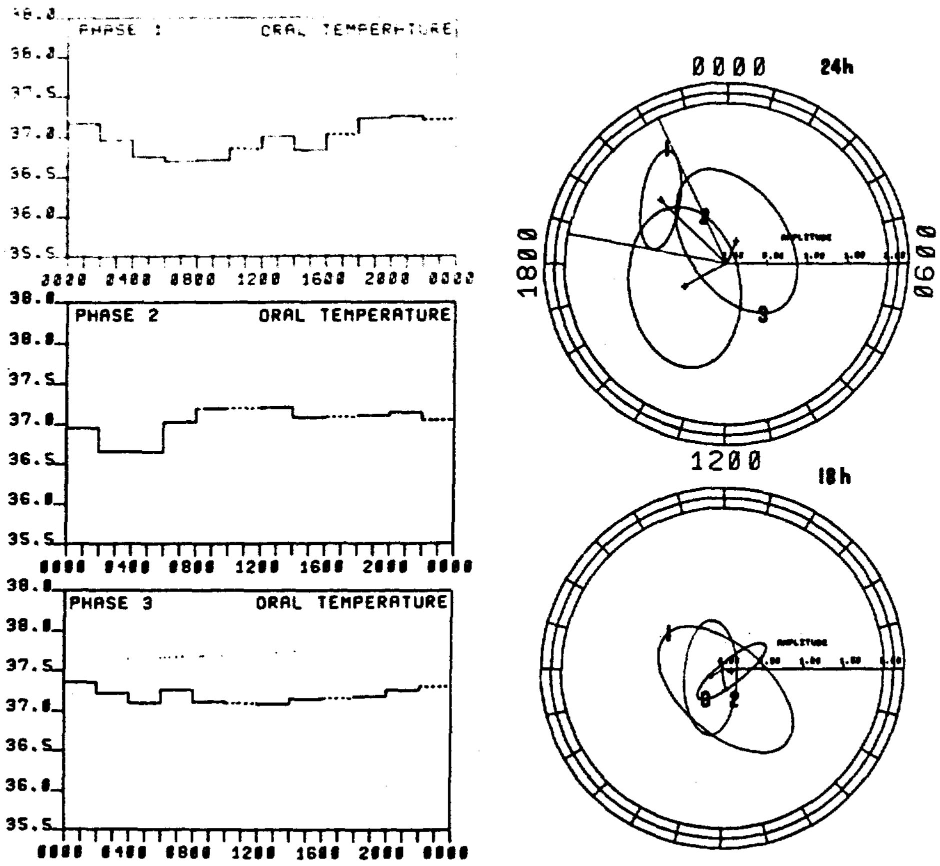


Figure 4

The cosinor analysis is a global statistical evaluation of the vectors defined by amplitudes and associated acrophase angles. Hence, it does not test whether the circadian amplitudes changed independent of the changes of acrophase angles, or vice versa. The t-test was used to test whether the 24-h oral temperature amplitude changed significantly from one phase to another. To test whether the TOPs changed from one phase to another, Rayleigh's z statistic (Batschelet[2,3]) was used. A significant Rayleigh z suggests a clustering of TOPs for the group of subjects. The Rayleigh's z was 6.38 for Phase 1, significant at 5% or better. For Phase 2, z was 2.15 (not significant), and z was non-significant at 0.67 for Phase 3.

Thus, for these seven men, loss of the group-synchronized 24-h oral temperature rhythm during Phase 3 was due to both an overall reduction in amplitude and a dispersion of TOPs. For Phase 2, where the group-synchronized 24-h rhythm disappeared for these men, its loss was more due to dispersion of TOPs; that is, the peak oral temperature value of one man occurred at a time far different from that of another.

As noted earlier, there was no doubt that the sleep-wakefulness cycle had been entrained by the 18-h watch-standing schedule. However, the group-mean-cosinor analysis revealed no 18-h rhythm in oral temperature during any of the three phases of this study (see Table 3 and Figure 4, the right-hand side, bottom).

The group-mean-cosinor analysis evaluates whether the group has a common, synchronized rhythm, where everyone in the group peaks at a similar local time. It will not indicate whether individuals in the group developed significant rhythms that are not in synchrony with each other. Therefore, the previous question was rephrased. Did the 18-h routine produce an 18-h oral temperature rhythm in individuals? To answer this question, two approaches were taken. First, the period of the strongest single rhythmic component in each man's oral temperature was determined. If the 18-h activity cycle is a dominant zeitgeber for oral temperature, we would expect an 18-h rhythmic component to be the strongest. Second, if the 18-h "day" exercised some influence over oral temperature, not as the determining factor but perhaps as a significant modulating factor, then an 18-h rhythm should be selected as one of the two components in the bisinusoidal analysis[16].

The results of the search for the strongest single rhythmic component for each of the seven submariners are given in Table 4.

TABLE 4 Period length which produced the best fit (One-wave analysis of seven submariners)

SUBJECT	PHASE 1 Period	r^2	PHASE 2 Period	r^2	PHASE 3 Period	r^2
ORAL TEMPERATURE						
1	18 h/c	0.25	24 h/c	0.21	24 h/c	0.25
2	24 h/c	0.32	(48 h/c	0.23)	44 h/c	0.23
3	17 h/c	0.12	24 h/c	0.22	26 h/c	0.31
6	36 h/c	0.15	18 h/c	0.09	20 h/c	0.32
8	24 h/c	0.31	24 h/c	0.43	36 h/c	0.27
9	25 h/c	0.17	25 h/c	0.22	24 h/c	0.43
10	32 h/c	0.16	16 h/c	0.14	25 h/c	0.25
Mean	25 h/c	0.21	22 h/c	0.22	28 h/c	0.29
SD	6.9	0.08	3.8	0.11	8.4	0.07
t*(re 24 h/c)	0.44 (N.S.)		-1.39 (N.S.)		1.39 (N.S.)	
t*(re 18 h/c)	2.74 (p = 0.03)		2.46 (N.S.)		3.27 (p = 0.02)	
Comment			Case No. 2 Omitted			
THAYER'S 'ACTIVATION'						
1	28 h/c	0.22	26 h/c	0.18	24 h/c	0.16
2	20 h/c	0.27	(48 h/c	0.20)	32 h/c	0.27
3	36 h/c	0.19	12 h/c	0.12	22 h/c	0.36
6	21 h/c	0.25	16 h/c	0.20	25 h/c	0.29
8	(48 h/c	0.18)	16 h/c	0.12	21 h/c	0.26
9	28 h/c	0.18	25 h/c	0.15	25 h/c	0.51
10	19 h/c	0.26	12 h/c	0.14	23 h/c	0.14
Mean	25 h/c	0.23	18 h/c	0.15	25 h/c	0.28
SD	6.6	0.04	6.2	0.04	3.9	0.13
t*(re 24 h/c)	0.50 (N.S.)		-2.43 (N.S.)		0.42 (N.S.)	
t*(re 18 h/c)	2.38 (N.S.)		-0.07 (N.S.)		4.83 (p = 0.003)	
Comment	Case No. 8 Omitted		Case No. 2 Omitted			

*t test for correlated means, in reference to either 24 h/c or 18 h/c, 5% or better, two tails.

The strongest component is defined by the largest r^2. During Phase 1, the period of the strongest or best-fit rhythmic component in oral temperature averaged 25-h with an r^2 of 0.21. This period was significantly different from 18-h, but not from 24-h. Two men (#1 and #3) did, however, exhibit the strongest rhythmic component at 18-h/cycle and 17-h/cycle. During Phase 2, the period of the strongest component at 18-h/cycle and 17-h/cycle. During Phase 2, the period of the strongest component averaged 22-h, which was not significantly different from either the 24-h or the 16-h cycle. Again, two men (#6 and #10) had the strongest rhythm at 18-h/cycle and 16-h/cycle. During Phase 3, the period length was significantly different from 18-h, but not from 24-h. In this Phase, none of the seven submariners showed the strongest rhythm near 18-h/cycle. It appears that the 18-h watch-standing schedule did not significantly alter the basic period of the oral temperature rhythm, although the small r^2 of 0.21 suggests considerable irregularity in the waveform.

Table 5 shows the results of the search for a "modulating" effect of 18-h watch-standing schedule on oral temperature.

TABLE 5 Two periods which produced the best fit (Two wave analysis of seven submariners)

SUBJECT	PHASE 1 Periods	r^2	PHASE 2 Periods	r^2	PHASE 3 Periods	r^2
ORAL TEMPERATURE						
1	18*/17	0.35	28/24	0.29	24/12	0.39
2	36/25	0.57	(48)/20	0.35	32/12	0.36
3	(48)/44	0.25	23/16	0.40	25/16	0.46
6	36/25	0.25	18/(8)	0.23	20/19	0.55
8	24/16	0.41	32/24	0.62	36/32	0.54
9	25/18	0.31	25/12	0.38	25/21	0.53
10	32/24	0.26	20/16	0.32	25/21	0.41
Mean		0.34		0.37		0.46
SD		0.12		0.12		0.08
THAYER'S "A[illegible]ATION"						
1	[illegible]/27	0.40	(48)/22	0.41	32/24	0.33
2	20/(8)	0.39	44/18	0.40	32/20	0.56
3	36/19	0.49	(48)/44	0.30	23/(8)	0.54
6	21/(8)	0.42	23/16	0.31	36/20	0.38
8	(48)/28	0.38	32/16	0.30	20/19	0.39
9	28/27	0.31	40/24	0.23	25/18	0.63
10	35/19	0.37	32/12	0.29	40/17	0.30
Mean		0.39		0.32		0.45
SD		0.05		0.06		0.13

* = in the unit of hours/cycle. A rhythm of 48-h/cycle was the lowest frequency fitted in the two-wave analysis, and it might be replaced by a lower frequency if a wider range of frequencies were offered for automatic selection. Similarly an 8-h/cycle was the highest frequency fitted, and it might be replaced by a higher frequency, given a wider range of choice.

In Phase 1, four groups of sinusoidal waves were selected: group one had the period length near to 18-h (chosen four times); group two had its period length near to 24-h (chosen five times), group three had its period near to 36-h (chosen three times), and group four had its period near to 48-h (twice). The 36-h period represents the second harmonic of a 72-h or 3-d period, which is the basic cycle in the 18-h watch-standing schedule That is, regardless of the local time that a man started his first six-hour watch, he will stand watch at the same local time after he completes 4 watches (6-h watch + 12 hours off x 4 = 72 hours = 3 days).

In Phase 2, two groups of sinusoidal waves were most prominent. Group one had a period length close to 18-h (chosen five times), while group two had a period length of approximately 24-h (chosen five times).

In Phase 3, four groups of sinusoidal waves were again selected group one had a period length of near 18-h (chosen three times), group two had a period length of near 24-h (chosen six times), group three had a period length of close to 34-h (chosen three times), and group four had a period length of 12-h (twice). Thirteen of the 42 waveforms given in Table 5 fall in the 23-25-hour range Eighteen of the remaining 29 seem to be more or less randomly distributed over the range from 8-h/c to 21-h/c. Over the three phases the r^2 averaged a modest .39. These data show disintegration of the normal 24-h periodicity in oral temperature, but the superimposition of cycles with a near 18-h period is not conspicuous. Living on the submarine appears to disrupt the circadian rhythm of oral temperature, but these data do not provide convincing evidence, in the form of prominent 18-h components, that the 18-h routine is, by itself, the primary cause of this disruption.

Thayer's Activation, Mood "Activity," Mood "Happiness." Tables 2 A and 2B give the basic observations of this study. The lower half of Table 2A shows the amplitudes and TOPs of the 24-h component in the TA scores of fifteen submariners. Table 2B gives the same information for MA and MH.

There was no significant difference between the Phase 1 and Phase 2 data of the twelve men participating in both Phases in terms of a 24-h TA rhythm amplitude. Similarly, no significant differences were found between Phase 1 and Phase 2 in terms of MA and MH.

For the seven men in all three phases, there was no significant change in 24-h amplitude from one Phase to another for TA, MA and MH. There were also no significant changes in the mean values of TA, MA and MH. Thus, the 18-h watch routine did not appear to affect the 24-h circadian amplitude of TA, MA and MH from one part of the patrol to another.

The group-mean-cosinor analysis was performed on the amplitudes and acrophase angles of the twelve submariners in Phase 1 and Phase 2. The results of this analysis are presented in Table 3. A group-synchronized 24-h rhythm was found for TA, MA, and MH only during Phase 1. The results of the GMCA of the seven men in all three phases are shown in Figure 5

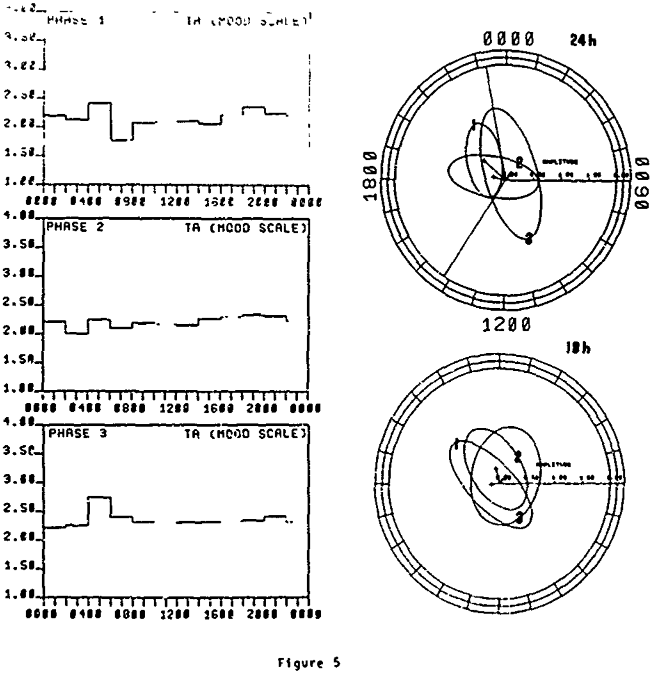


Figure 5

The ellipses in the cosinor plot are drawn to show a 90% confidence area. The GMCAs of MA and MH showed that Phase 1 data did not have a group-synchronized 24-h rhythm. This evaluation is inconsistent with the results of a similar analysis applied to the larger group of twelve men, most likely due to the loss of statistical power resulting from use of a smaller sample. For these seven men no group-synchronized 24-h rhythm was found for TA, MA, or MH during Phases 2 or 3.

To test whether the acrophase angles changed from one Phase to another, independent of the changes in amplitudes, Rayleigh's $\underline{z}$ was calculated for all three variables in each Phase. The largest $\underline{z}$ was 2.71 ($p<.10$) for TA in Phase 1, but it did not reflect a significant concentration of TOPs within a narrow time interval. Thus, loss of the group-synchronized 24-h rhythms in TA, MA and MH during Phases 2 and 3 appears to be due mainly to dispersion of the TOPs.

The GMCAs for an 18-h rhythm in TA, MA, and MH revealed that there was only one group-synchronized 18-h rhythm: MH during Phase 2 (see Table 3).

The results of a search for the strongest rhythmic component in TA for each of the seven men are given in the lower half of Table 4. During Phase 1, the average period of the strongest or best-fit rhythmic component in TA was 25-h, with an r^2 of 0.23. This period was not significantly different from either 24-h or 18-h, but it was clearly closer to 24-h. Only two men had the strongest rhythmic component closer to 18-h: one with a 19-h, and another with a 20-h cycle. During Phase 3, the period of the best-fit rhythmic component <u>averaged</u> 18-h. This period length was not, however, significantly different from 24-h. Two (different) submariners had the strongest rhythm at 16-h/cycle. During Phase 3 the best-fitting period length averaged 25-h with an r^2 of 0.28. This period was significantly different from 18-h, but not from 24-h. None of the seven submariners showed the strongest rhythm near 18-h in Phase 3.

Thus, it appears that the 18-h watch-standing schedule did not exercise a strong influence over the individual's rhythm in TA. Phase 2 data came the closest in showing 18-h/c as a group average, but close examination shows that this 18-h average is misleading, because it was affected by the data from two submariners who had 12-h cycles.

The lower half of Table 5 shows the results of a search for a modulating effect of the 18-h watch-standing schedule on the Thayer Activation scale.

In Phase 1, five groups of sinusoidal waves could be identified. group one had a period of 8-h (chosen twice), group two had periods near 20-h (chosen four times), group three had periods near 27-h (chosen four times, group four had a period of 36-h (twice), and group five had a period of 48-h (twice). In Phase 2, three main groups of sinusoidal waves could be identified. group one had a long period length of 32-h to 48-h (chosen seven times), group two had periods near 24-h (chosen three times), group three had periods near 16-h (three times). In Phase 3, three groups of sinusoidal waves could be identified· group one near 180h (six times), group two near 24-h (three times), and group three near 36-h (four times). Thus, the eighteen-hour routine may have played a modulating role in the TA, especially during Phase 3.

Simpson, Lobban and Halberg[25] investigated the relative strength of "nature" over "nurture" in rhythmic components of urinary data. In their study, the subjects lived and "nurtured" under a 21-h day for up to 7 weeks during a period of perpetual daylight in the Arctic summer. Simpson et al. anticipated a progressive adaptation of the subjects to the 21-h day to be reflected by

gradual weakening of the 24-h rhythm and the appearance of a 21-h rhythm of progressively greater strength. For the purpose of expressing the change in rhythm, they devised the circadian amplitude ratio (CAR). This ratio is obtained by dividing the amplitude of 24-h rhythm by the amplitude of the 21-h rhythm. A CAR larger than one represents a predominance of "nature's" rhythm, whereas a predominance of "nurture's" rhythm is indicated when the CAR is smaller than one.

In the present study, a CAR was calculated for the oral temperature data by dividing 24-h oral temperature amplitude by the 18-h oral temperature amplitude. In Phase 1, the average CAR was 1.61 $\pm$ 0.99 (sd). In Phase 2, the CAR averaged 1.36 $\pm$ 0.80. In Phase 3, it was 1.60 $\pm$ 1.02. These CARs did not differ significantly from each other.

The CAR was also calculated for TA. Average CARs for Phases 1, 2, and 3 were 1.32 $\pm$ 0.81, 2.03 $\pm$ 1.65, and 1.82 $\pm$ 0.08 respectively. Again, these did not differ significantly from each other.

DISCUSSION

In our study, sleep and wakefulness was found to show a clearly shortened cycle in all three phases of the patrol. Its average period was 18.8 h/cycle, and it could account for an average of about 70% of the total variance in the sleep-wakefulness data. Some of the submariners developed two rhythmic components in the sleep-wakefulness or activity cycle: one rhythm oscillating near 18-h/cycle and another near 25-h/cycle, the latter being much weaker. For a majority of the men, an 18-h watch routine entrained an 18-h "day."

The sleep-wakefulness or activity cycle has been shown to be entrained by a variety of strong zeitgebers. Five reports[12,13,14,25,27] recently summarized by Aschoff[1] show that the activity cycles of human subjects may be entrained from periods of 20-h/c to 30 h/c under the influence of strong environmental and social zeitgebers. Our findings expand the lower boundary of the range of entrainment of the activity cycle from 20-h/c down to 19-h/c. Some submariners also showed small but significant peak activity rhythms near the 25-h/cycle. Whether this 25-h cycle represents a free-running rhythm could not be determined because the resolution (one hour) used for analysis was not of required precision. (A 0.1-hour resolution was used by Simpson[25] and Colquhoun et al.[5,6])

More submariners showed the secondary peak near 25-h/cycle early in the patrol: during Phase 1 six out of eleven men exhibited such a peak. As the patrol progressed in time and the men worked continuously under the 18-h watch-keeping system, fewer showed the secondary peak near 25-h/cycle. During Phase 2, four out of eight submariners exhibited the secondary peak, while only two out of seven showed the secondary 25-h peak during Phase 3. This trend suggests that the activity cycle would become progressively monorhythmic at 18-h/c as the submariners continue to live under the 18-h schedule.

The impact of an 18-h day on the circadian rhythm of oral temperature was found to be quite different from that found for the activity cycle. First, the 18-h day eliminated the group-synchronized 24-h rhythm in oral temperature by the 40th day of the voyage. Schaefer et al.[20] also observed that the 24-h cycles in physiological functions, such as body temperature, pulse rate, respiration rate, and blood pressure, were disrupted among submariners by working under an 18-h watch-standing schedule. In an unpublished analysis of data collected from seven of the men

studied by Schaefer et al., Haus (personal communication) found that the clear circadian rhythm observed during the outfitting baseline period had disappeared in the early period (days 7-17) under the 18-h routine. Haus observed, however, that some submariners regained a 24-h rhythm in body temperature by days 26-41. In the present study, a recovery of the group-synchronized 24-h rhythm in oral temperature was not observed. Colquhoun et al [5,6] reported on eight sonar ratings working 4-h watches in a rapidly rotating cycle, and found a similar effect on the oral temperature cycle. Only one of Colquhoun's subjects did not show a change in the 24-h body temperature rhythm. Two of his subjects experienced the disintegration of the normal 24-h rhythm into shorter periods of 4-h and 8-h.

In a series of papers, Simpson et al.[21,22,23,24,25] examined the effects of a 21-h day on subjects spending their summer in Spitzbergen (at latitude 78°N) or on Devon Island, Northwest Territory, Canada (latitude 75°N). The subjects, eight in the Spitzbergen study and five in the Devon Island study, slept in trapper's huts or darkened tents in their own community under perpetual daylight. A detailed frequency analysis was performed on a variety of urinary variables and two performance measures. In these studies, life on a 21-h routine did not disrupt the 24-h rhythm in the manner observed for an 18-h routine, but produced a rhythm of 21-h/c, and another rhythm of 24.2-h/c. Thus the effect of a 21-h day on the maintenance of a 24-h rhythm appears to be much less severe than that expected from an 18-h day.

In the present study, a decreased circadian amplitude was observed in oral temperature as the patrol continued. This result confirms the Schaefer et al[20] report of the decrease in oral temperature amplitude in five submariners. Colquhoun, et al.[5,6] also found a progressive flattening in the mean amplitude of the body temperature rhythm. Additionally, Colquhoun, et al noticed an increase in the average oral temperature of their subjects during the patrol. The present study also confirms this second observation.

Life on an 18-h routine also eliminated the group-synchronized 24-h rhythm in level of "activation," as well as 24-h rhythms in Mood "Activity" and Mood "Happiness."

Since the amplitudes of these psychological variables did not appear to decrease, loss of the group synchronized 24-h rhythm was caused mainly by a wide scatter of TOPs. Analysis confirmed that the once tightly concentrated TOPs scattered so that the peak value of a mood measure of one individual occurred at a time widely separated from the time the peak value was observed for another. A similar dispersion of TOPs occurred for oral temperature. This contributed, along with the reduced amplitudes, to the loss of the group-synchronized 24-h rhythm in oral temperature.

The 18-h living routine in this study exerted a strong influence on the 24-h rhythms examined. It altered the 24-h rhythm of the activity cycle and entrained it to an 18-h rhythm. The 18-h routine also altered the 24-h rhythms in oral temperature, level of "activation," and two mood scales, but failed to produce a group-synchronized 18-h rhythm in oral temperature in any of the three phases. The group-mean-cosinor analysis showed also that the group-synchronized 18-h rhythm did not develop over the period of prolonged submergence in TA, MA, or MH, except MH during Phase 2. The finding of a significant 18-h rhythm for MH during Phase 2 may well have been a chance event, since 24 Hotelling's T^2's (the cosinor analysis) were calculated and evaluated at the 5% level.

Haus (personal communication) reported that the 18-h routine induced a group-synchronized 18-h rhythm in the submariners studied by Schaefer, et al. During the outfitting and up to 24 days of the underwater patrol, there was no significant 18-h cycle in the body temperature of Schaefer's subjects. However, a significant 18-h component in body temperature was detected during the period from 26 to 41 days.

The failure of the 18-h routine to entrain a simple 18-h rhythm does not mean that the 18-h day had no influence over individual submariner's oral temperature and psychological states. A detailed individualized analysis was applied to oral temperature and TA data obtained from the group of seven submariners. Results showed that the 18-h routine did not influence individuals' rhythms to the extent that the 18-h component was usually the strongest one present. In some individuals, the 18-h rhythm was the strongest, but these men were not a majority. As a group, the period of the strongest rhythm was closer to 24-h than to an 18-h. During Phase 2, TA came the closest to showing a period (18-h) different from 24 hours. A close examination of the data revealed, however, that the second harmonic of a 24-h period (12-h) played a part in bringing the group average to near 18-h/c (see Table 5). Thus, even on individual analyses, the 18-h routine did not entrain physiological and psychological functions to an 18-h rhythm.

The bisinusoidal (two-wave) analysis seemed to offer a small amount of support for the hypothesis that the 18-h rhythm did exert some modulating influence. This analysis revealed additional rhythms near 36-h/c and 48-h/c. The 36-h period is harmonically related to both the activity cycle (18-h) and the basic period of the watch rotations (72-h). Persistent 24-h rhythms were also detected in some of our subjects. Thus, the submariners exhibited complex rhythmic patterns which varied from one individual to another, where the major rhythmic components were 18-, 24-, and 36-h/c, and the harmonics and subharmonics of 24-h/c (8-, 12-, and 48-h/c). Similar complexity was observed by Schaefer, et al.[20] among submariners in response to the 18-h routine, and also by Colquhoun, et al.[5,6] among subjects standing 4-h watches in a rapid rotation.

A circadian amplitude ratio was calculated to see whether there was a progressive adaptation, as defined by Simpson, et al.[25], in the submariners during the 10-week submergence. The results indicated a general absence of such adaptation to the 18-h routine. Similar lack of adaptation (perhaps excepting a rhythm in water excretion) was observed by Simpson, et al.[25] for subjects living under a 21-h routine for up to 7 weeks.

Thus, the findings of this study showed that the 18-h routine did not entrain oral temperature, TA, or two mood scales. Aschoff[1], in his review of the literature, showed that body temperature had a narrower range of entrainment than the activity cycle and that it tended to free-run when a strong zeitgeber was too far away from a 24-hour period. Kleitmann[11] had reported earlier that an artificial 12-h watch-standing schedule would not entrain submarine personnel to a similar rhythm. Thus, when the dominant zeitgeber was 20-h/c, body temperature would tend to free-run at approximately 25-h/c. Whether the submariners in our study did have a free-running rhythm could not be decided.

Since the sleep-wakefulness cycle was entrained by the 18-h routine but oral temperature and psychological state were not, a spontaneous internal desynchronization[27] may be an unavoidable consequence of life under the 18-h watch-standing schedule. Simpson, et al [21,22,25] reported a

potential performance degradation of 15% or more during the early phase of life under a 21-h routine, resembling a "jet lag" of 3-h. The performance tests examined by Simpson and others were limited to hand-grip strength and eye-hand coordination test. There is as yet no definitive information about performance and psychological states as they are affected by chronic dyschronism due to life under unusual temporal routines.

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FIGURE LEGENDS

Figure 1 Sample page of the Personal Activity Log. Activity information was obtained from the first five rows, where submariners chose the most appropriate row and drew a line from the time they started until the time they stopped. The line was measured to the nearest 1/2 h. The mood scales appear below the graphic activity record.

Figure 2 Aschoff's bars[27] representing twelve wake-sleep cycles of submariner No. 14 during Phase 1 of the patrol. Waking time is shown by the black section of each bar. Watches are shown by thickenings below, and extra duty is shown by thickening above the black section. The white sections represent sleep periods. This submariner had a sleep-wakefulness rhythm of an 18-h/cycle (r^2 - 0.87).

Figure 3 Three chronograms (left-hand side) and three plexograms (right-hand side) of oral temperature. The chronograms[9] display individual data points as they were observed during the patrol. The plexograms[9] show not only each data point (a square), but also two-hourly means as a connected line starting from midnight. Thus, in the plexograms, all observations made during the period from midnight to 2 a.m. were averaged and the average shown as a flat line covering a two-hour period. The broken lines in the plexograms shows the time periods where no observations were obtained. In the absence of data for a two-hour epoch, the mean value of the two adjacent epochs was plotted. The circadian dip in oral temperature can best be seen in the Phase 1 plexogram. The data in this figure was obtained from submariner No. 1 of this study.

Figure 4 Plexograms of the oral temperature averages of the seven subjects who are asterisked in Table 2 are shown on the left-hand side. On the right-hand side, the top "clock face" shows a group-mean-cosinor plot[9] of oral temperature for each Phase with 95 confidence ellipses, evaluated at 24-h/cycle. The bottom clock face shows a group-mean-cosinor plot of oral temperature evaluated at the 18-h cycle. When only seven submariners are examined by the group-mean-cosinor analysis, as shown in this Figure, a significant group-synchronized 24-h rhythm is observed for Phase 1 data. When all twelve submariners' data are analyzed in this way, however, a significant group-synchronized 24-h rhythm is detectable in both Phase 1 and Phase . data (see the text and Table 3 for details). No group-synchronized 18-h rhythm in oral temperature was found in any of the three Phases.

Figure 5 Plexograms of Thayer's "Activation" mood scores from seven men are shown on the left-hand side. The top "clock face" shows group-mean-cosinor plot of Thayer's "Activation" mood scores for each Phase with 90 confidence ellipses, evaluated at 24-h/cycle. The bottom clock face shows TA evaluated at 18-h/cycle.

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A group of nuclear submariners was studied to examine whether an 18-h routine imposed by a watch-standing schedule of 6-h on, 12-h off during a prolonged submerged patrol affected the 24-h circadian rhythm in oral temperature, Thayer's activation, Mood "Activity" and Mood "Happiness." The submariners were observed during three sections of the patrol: Phase 1, the beginning 8-day period; Phase 2, the middle of the voyage; and Phase 3, the last 7-8 day period of the 10-week voyage. The group-synchronized 24-h

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rhythm in oral temperature disappeared during Phase 3. The group-synchronized 24-h rhythms in Thayer's activation and in Mood "Activity" and "Happiness" disappeared during Phases 2 and 3. A group synchronized 18-h rhythm was not produced in any of the variables in any Phase of this study, except MH during Phase 2. Periodicity analysis of individuals' data showed that a loss of 24-h rhythmicity in oral temperature was due not only to reduced circadian amplitude but also to a dispersion of TOPs. Loss of 24-h rhythm in "Activation," "Happiness," and "Activity" was predominantly due to a wider dispersion of TOPs. The 18-h routine did appear to exert a small modulating effect on rhythmic activity in the variables examined in this study.

Since the sleep-wakefulness cycle was well entrained by the 18-h routine, the submariners experienced a spontaneous internal desynchronization between the activity cycle on the one hand and the cycles of oral temperature and psychological states on the other. The performance and health consequences of this chronic desynchronism have yet to be explored. We suggest further research to determine the usefulness of an index of synchronization among the physiological and psychological variables, and the relationship of the desynchronizing effects to performance and health.